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Effects of Fertilization on Growth and Foliar Nutrients of Red Alder Seedlings

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Abstract

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Effects of P, K, Ca, Mg, S, Co, and Mo fertilizers on growth and foliar nutrients of red alder seedlings potted in Grove, Bunker, and Wishkah forest soils were determined. Growth in Grove soil was stimulated most by P, Ca, and P + Ca + Mg + K + S. Growth in Bunker soil was improved only by P. In Wishkah soil, best growth was obtained when P was used alone; all fertilizer mixtures produced less growth. Results indicated the potential of fertilizer to increase alder production and suggested caution in using fertilizer mixtures because they may materially reduce growth response.

Keywords: Fertilizer effects, growth response, nutrients, red alder, seedling growth.

Summary

Two experiments were conducted to determine effects of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), cobalt (Co), and molybdenum (Mo) fertilizers on growth and foliar nutrients of red alder (*Alnus rubra* Bong.) seedlings grown in three different forest soils in a lathhouse. Soil series used were Grove and Bunker in experiment 1 (1982) and Grove and Wishkah in experiment 2 (1983). Test soils are among those soils found under natural stands of alder in western Washington. In experiment 1, fertilizers were: (1) triple superphosphate (P); (2) KCl (K); (3) $CaCo_3$ (Ca); (4) $MgCl_2$ (Mg); and (5) Na_2SO_4 (S). In experiment 2, fertilizers were: (1) P; (2) P + Ca; (3) P + Ca + Mg; (4) P + Ca + Mg + K;(5) P + Ca + Mg + K + S; (6) P + Ca + Mg + K + S + $CoCl_2$(Co); and (7) P + Ca + Mg + K + S + Co + MoO_3 (Mo). In both experiments, fertilization was done in May. In experiment 1, fertilizers were mixed with the top 2 cm of mineral soil. In experiment 2, mineral soil was covered with a layer of forest floor, and fertilizers were spread over the forest floor without mixing. Growth in the unamended soils was much better in Grove, with or without forest floor, than in the Bunker or Wishkah soils; the latter soils were especially low in extractable P. Fertilization significantly affected growth in all test soils. Growth in the Grove soil was enhanced most by the P, Ca, and P + Ca + Mg + K + S fertilizers. Growth in Bunker soil was increased only by the P treatment; all other fertilizers were ineffective. Growth in Wishkah soil was improved most by the P fertilizer alone; all fertilizer mixtures produced significantly less growth than that obtained with P alone. Foliar nutrient concentrations of the unfertilized trees were generally within the range of values reported in the literature for red alder. Fertilization influenced nutrient concentrations, and trends varied by soil and fertilizer treatment. Amounts of nutrients in the leaves were significantly increased by the effective fertilization treatments, reflecting enhancement of dry matter production and nutrient uptake and use. Nutrient additions resulting from fertilization differed by soil, with the macronutrients showing the largest gains. Results indicated the potential of fertilizer, especially P fertilizer, to increase growth. Results also suggested caution in using fertilizer mixtures because they may materially reduce growth response.

Contents

Introduction

Red alder (*Alnus rubra* Bong.) is the major hardwood species in the Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) region of the Pacific Northwest. Red alder is known for its rapid juvenile growth, for its ability to fix atmospheric nitrogen (N), and for adding nutrient-rich leaflitter to the soil (Gessel and Turner 1974, Radwan and others 1984, Tarrant and Trappe 1971). The inherent characteristics of alder make it an excellent choice for short-rotation, biomass-for-energy plantations. Alder is also gaining importance because of the steady increase in the commercial value of its wood. In addition, the species has been recommended for planting on surface-mine spoils and has been suggested as a biological source of nitrogen for use in admixtures or crop rotations with conifers (DeBell 1979).

Presently, little literature exists on the nutrition of alder species, including red alder. European black alder (*Alnus glutinosa* [L.] Gaertn.) is reported to require molybdenum (Mo) (Becking 1961) and cobalt (Co) (Bond and Hewitt 1962) for symbiotic N_2-fixation. Pregent and Camire (1985) estimate critical levels of selected nutrients in foliage of green (*Alnus crispa* [Ait.] Pursh) and black alder. Lime and phosphorus (P) enhanced growth of black alder (Seiler and McCormick 1982). Applications of Co (Russell and others 1968) and P and calcium (Ca) fertilizers (Hughes and others 1968) improved growth of red alder. Still, much more nutritional information about alder is needed if maximum growth and N_2-fixation are to be obtained.

This study was designed to assess effects of various fertilizers applied, singly and in combination, to red alder seedlings grown in different soils.

Materials and Methods

The study consisted of two separate experiments, with seedlings from the same seed source used in both experiments. Experiment 1 (1981-82) compared untreated controls and five different fertilizers applied singly at two different rates each. In experiment 2 (1982-83), comparisons were made between controls, a single fertilizer, and six different fertilizer mixtures.

Test Soils

The soil series used in the study were Grove and Bunker for experiment 1 and Grove and Wishkah for experiment 2. These soils differ greatly in many of their properties, and they are among the soils found under natural stands of red alder in western Washington. For each soil series, the forest floor and the underlying mineral soil to a depth of 20 cm were collected separately. Large pieces of stems, roots, and rocks were removed and samples were mixed thoroughly. Soils were placed in 7.6-L plastic pots. Each pot, with a top of about 3×10^{-6}ha, contained about 6 kg of mineral soil, on an air-dry basis. In experiment 2, mineral soil in each pot was covered with about 100 g of forest floor spread evenly over the top to simulate natural conditions.

Representative subsamples of the mineral soils were passed through a 2-mm sieve, and sieved subsamples were used for determining selected chemical characteristics as shown below. Soil subsamples used to determine N and all samples of forest floor materials were ground to a fine powder before analysis.

Test Seedlings

Seeds for both experiments were collected from a single tree growing at Capitol Forest, west of Olympia. In July (1981 for experiment 1 and 1982 for experiment 2) seeds were sown in styroblock containers filled with 1:1 (v/v) mixture of peat moss and vermiculite. Seeds in the cavities were covered with a thin layer of silica grit to discourage algal growth, and the containers were kept in a roofed lathhouse. Water was added as required during the first 2 weeks after sowing. Seedlings were then watered with a dilute

(1:1, v/v) nutrient solution (Hoagland and Arnon 1950) once a week, and cavities were flushed with water once a month to prevent accumulation of excess salts. Five weeks after sowing, seedlings were thinned to one per styroblock cavity, and seedlings were inoculated with red alder endophytes from a single preparation of crushed-nodule inoculum. In mid-September, addition of nutrient solution was discontinued to slow growth and encourage budset and cold hardiness.

In early spring 1982 and 1983 (for experiments 1 and 2, respectively), the cavities were flushed with water several times to remove as much of the nutrients remaining in the potting mixture as possible. Seedlings were individually planted in the plastic pots containing the different soils. A three-seedling group served as the basic experimental unit. Three groups of three seedlings each (three replications and nine seedlings) were used for each soil-fertilizer treatment in each experiment. Seedlings were placed, as groups of three, at random on low wooden benches in the roofed lathhouse.

Treatments

Experiment 1 consisted of 10 fertilization treatments and an untreated control (C). Triple superphosphate, potassium chloride, calcium carbonate, magnesium chloride, and sodium sulfate were used as sources of P, potassium (K), Ca, magnesium (Mg), and sulfur (S), respectively.The fertilizers were applied singly on an area basis at low and high rates equivalent to 150 and 300 kg P/ha; 100 and 200 kg K/ha; 1200 and 2400 kg Ca/ha; 75 and 150 kg Mg/ha; and 75 and 150 kg S/ha. The nutrients were applied to the seedlings in May 1982 by mixing the fertilizer with the top 2 cm of soil and watering the pots the same day.

Experiment 2 had seven fertilization treatments and an untreated control. Triple superphosphate, calcium carbonate, magnesium chloride, potassium chloride, sodium sulfate, cobalt chloride, and molybdenum trioxide supplied the nutrients P, Ca, Mg, K, S, Co, and Mo. The fertilizers were applied in that order and in an additive manner to yield the seven fertilization treatments: P; P + Ca; P + Ca + Mg; P + Ca + Mg + K; P + Ca + Mg + K + S; P + Ca + Mg + K + S + Co; and P + Ca + Mg + K + S + Co + Mo. Rates of application per hectare, on an area basis, were equivalent to 300 kg P; 1800 kg Ca; 75 kg Mg; 100 kg K; 75 kg S; 0.1 kg Co; and 0.5 kg Mo. Fertilizers were placed around the potted seedlings on top of the forest floor, without mixing, to simulate field fertilization. Seedlings were watered the same day fertilizers were applied.

Growth Measurements

Height and diameter of the test seedlings were determined before treatment in May and in September when the seedlings were harvested at the end of each experiment. At harvest, shoots and roots were separated by clipping at the root collar. The eight healthiest, fully expanded leaves were cut from each plant to determine the average weight of mature leaves; the same material was used for foliar chemical analysis. Roots were washed free of soil, and excess moisture was removed with blotting towels. Shoots, roots, and leaves were cut up and dried to constant weight at 65 °C. Height, diameter growth, and dry weight of shoots, roots, and leaves were calculated.

Processing and Chemical Analysis of Foliage

Ovendry leaves, separated by replication, soil, and treatment, were ground to 40 mesh in a mill and stored in plastic containers until analyzed.

Total N and total S were determined, respectively, by the micro-Kjeldahl procedure (Bremner and Mulvaney 1982) and by the turbidimetric method of Butters and Chenery (1959). Other nutrients were determined as follows: P by the molybdenum blue method (Chapman and Pratt 1961), and K, Ca, Mg, copper (Cu), iron (Fe), zinc (Zn), and manganese (Mn) by atomic absorption (Perkin-Elmer Corporation 1976).

Chemical Analysis of Soils and Forest-Floor Materials

Mineral soils and forest-floor materials were characterized by determining pH on 1:1 mixtures with water by glass electrode, total N by the Kjeldahl method (Bremner and Mulvaney 1982), total S by turbidimetric method (Butters and Chenery 1959), and Bray-2-extractable P according to Bray and Kurtz (1945). Mineral soils were also analyzed for cation exchange capacity by NH_4OAc extraction (Chapman and Pratt 1961) and for exchangeable K, Ca, and Mg (NH_4OAc extraction) by atomic absorption (Perkin-Elmer Corporation 1976).

Statistical Analysis

For each experiment, growth and foliar-nutrient data were treated by analysis of variance to assess effects of soils and fertilization treatments; means within soils were separated by Tukey's test as required (Snedecor 1961). Differences were considered significant at $P < 0.05$.

Results and Discussion

The Study Soils

Soil samples used in the study differed in many of their characteristics (table 1). Parent material of the mineral soil was glacial for Grove and Wishkah and basalt for Bunker. Mineral soils of Bunker and Wishkah were particularly higher in N, S, and cation exchange capacity and lower in extractable P than was Grove soil. Mineral soil of Wishkah was lowest in pH and exchangeable K and Ca, and Bunker soil was highest in exchangeable Mg. Forest-floor materials varied in pH, N, S, and P in the same order as did the mineral soils. Nitrogen and S were higher and P was lower in forest floors of Bunker and Wishkah than in those of Grove. The forest floor of Wishkah had the lowest pH and that of Bunker had the lowest P.

Table 1—Selected characteristics of study soils

	Grove soil		Bunker soil		Wishkah soil	
Item	Mineral soil	Forest floor	Mineral soil	Forest floor	Mineral soil	Forest floor
Soil parent material	Glacial	—	Basalt	—	Glacial	—
pH	5.55	5.02	5.20	4.50	4.48	3.80
Kjeldahl N (percent)	.20	.54	.30	.82	.30	.72
Total S (percent)	.02	.07	.05	.10	.05	.10
Bray 2-extractable P (p/m)	65.0	130.0	5.2	24.0	3.5	45.0
Cation exchange capacity (meq/100 g)	23.7	—	37.2	—	34.6	—
Exchangeable (NH_4OAc) K (meq/100 g)	.4	—	.5	—	.2	—
Exchangeable (NH_4OAc) Ca (meq/100 g)	2.0	—	2.2	—	.6	—
Exchangeable (NH_4OAc) Mg (meq/100 g)	.3	—	.6	—	.3	—

Seedling Growth

In both experiments, seedling growth was very slow in the cool spring. Growth accelerated with the higher temperatures during the summer and was essentially complete at harvest in September. Harvested seedlings were free of disease and insect damage. Roots were variously nodulated with great differences in nodule size. Nodule weights were not determined, though, because collecting the nodules quantitatively and without root fragments was impossible.

In both experiments, significant soil, fertilizer, and soil x fertilizer interactions were found in all the growth variables examined.

Experiment 1—Without fertilizer, seedling growth was much better in Grove than in Bunker soil (table 2). This was shown, to varying degrees, by the different variables measured; for example, seedling dry weight and height growth were, respectively, 17.4 and 7.6 times greater in Grove than in Bunker soil. The two soils differed greatly in their content of available nutrients (table 1).

Fertilization significantly affected growth in both soils, and effects varied by fertilizer and rate of application. In the Grove soil, several fertilization treatments were effective. Growth was enhanced most, however, by the P and Ca fertilizers, although concentrations of the native, extractable P and exchangeable Ca in the soil seemed adequate (table 1). The favorable effects of the P and Ca fertilizers agreed with earlier findings for seedlings of red alder (Hughes and others 1968) and European black alder (Seiler and McCormick 1982).

Averaged over both the low and high treatments, fertilization increased height growth and seedling dry weight over the controls by 64 and 94 percent for P and by 61 and 71 percent for Ca (table 2, fig. 1). S was the least effective fertilizer in Grove soil, although total S in the soil seemed low (table 1).

Growth in the Bunker soil was significantly improved only by the P fertilizer, which produced dramatic results; average responses to this fertilizer of increased height growth and seedling dry weight over the controls were 895 and 1780 percent, respectively (table 2, fig. 1). The Bunker soil was especially low in native, extractable P (table 1), and this element was clearly the primary nutrient limiting growth in that soil. Without P additions, seedlings were visibly stunted, and many leaves had brown spots. The purplish color of leaves typical of P deficiency in other plant species (Sprague 1964) was not observed, however.

Table 2—Effect of fertilization on growth of red alder seedlings in 2 forest soils (experiment 1)[1]

Treatment	Diameter growth	Height growth	Leaf dry weight	Root dry weight	Shoot dry weigh
	Millimeters	*Centimeters*		*Grams*	
			GROVE SOIL		
C	6.2d	32.5c	0.28e	3.1c	5.6d
P, low	6.7bcd	49.4ab	.42b	4.0bc	9.0bc
P, high	8.1a	57.3a	.54a	6.2a	14.6a
K, low	6.3d	45.1b	.31de	3.5bc	7.0cd
K, high	6.8bcd	51.9ab	.33cde	4.4abc	8.7bc
Ca, low	7.1a-d	46.9ab	.42b	4.7abc	8.7bc
Ca, high	7.6ab	57.5a	.49ab	5.2ab	11.2b
Mg, low	7.4abc	49.9ab	.41bc	4.8abc	9.5bc
Mg, high	6.6cd	48.0ab	.39bcd	3.6bc	8.4c
S, low	6.9bcd	44.2bc	.34b-e	3.6bc	7.4cd
S, high	6.9bcd	43.3bc	.37bcd	3.8bc	7.6cd
			BUNKER SOIL		
C	1.2c	4.3b	0.04b	0.2b	0.3b
P, low	6.2a	41.7a	.33a	3.1a	6.3a
P, high	6.4b	43.8a	.35a	2.6a	6.7a
K, low	1.0c	3.0b	.03b	.2b	.3b
K, high	.9c	3.1b	.03b	.2b	.2b
Ca, low	.8c	3.4b	.04b	.2b	.3b
Ca, high	1.0c	3.5b	.03b	.2b	.3b
Mg, low	1.0c	3.9b	.03b	.2b	.3b
Mg, high	1.0c	3.8b	.03b	.2b	.3b
S, low	1.1c	3.6b	.03b	.2b	.3b
S, high	1.0c	3.2b	.03b	.2b	.2b

[1] C = untreated control. "Low" and "high" refer to application rates as follows: 150 and 300 kg P/ha, 100 and 200 kg K/ha, 1200 and 2400 kg Ca/ha, 75 and 150 kg Mg/ha, and 75 and 150 kg S/ha. Values are averages of 3 replications each. Within each soil, averages in the same column followed by different letters are significantly different at $p < 0.05$.

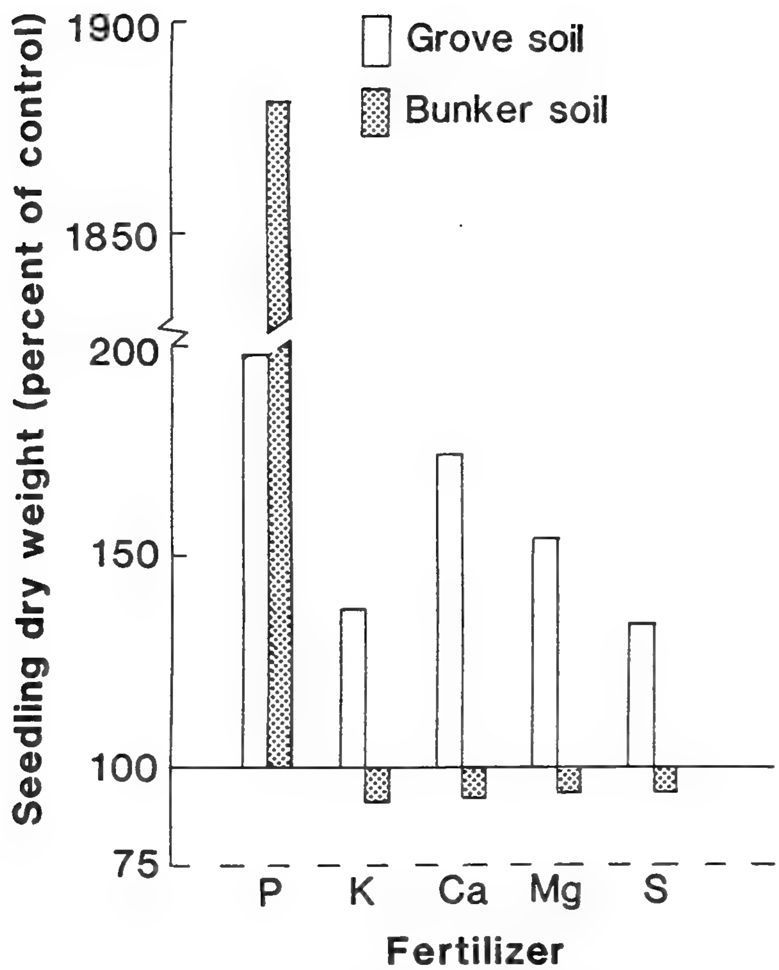

Figure 1—Effect of different fertilizers on seedling dry weight of red alder. Fertilizers were applied singly. Fertilizer sources and application rates are given in the text. Values are averages of two application rates.

Experiment 2— As in experiment 1, alder seedlings grew well in the unfertilized Grove soil (table 3). Seedling performance in that soil was not noticeably different in this experiment from that observed in experiment 1; forest floor was used to cover the mineral soil only in experiment 2. Tree growth in the unamended Wishkah soil was poor. Growth in that soil, however, was better than that in Bunker soil used in experiment 1 (table 2). This result may be explained by the additional supply of P provided by the Wishkah forest floor used to cover the mineral soil; no forest floor was used in the first experiment.

As with experiment 1, fertilization affected seedling performance in the two soils. Clearly, the forest floor placed on top of the mineral soil did not impede movement of the fertilizers, including P, to the roots. In both soils, all fertilizers increased growth, although not all increases were significant. Increases in dry weight of the Grove seedlings over the controls were lowest (21 percent) with the P + Ca + Mg + K fertilizer mixture and highest (66 percent) when S was added to that treatment (fig. 2). The reason for this difference is not readily apparent, although nutrient interactions may have been involved. In the Wishkah soil, growth was stimulated most by the P fertilizer alone, followed by the P + Ca mixture; increases in dry weight of seedlings over the controls by these treatments were 312 and 100 percent, respectively (fig. 2). All fertilizer mixtures produced significantly less growth than did P alone (table 3, fig. 2). Response to P was expected because the soil was low in native, extractable P (table 1). As with

Table 3—Effect of fertilization on growth of red alder seedlings in 2 forest soils (experiment 2)[1]

Treatment	Diameter growth	Height growth	Leaf dry weight	Root dry weight	Shoot dry weight
	Millimeters	*Centimeters*	Grams		
			GROVE SOIL		
1	4.6b	38.7b	0.28c	4.2c	6.8c
2	5.6a	51.0ab	.40ab	5.9a	11.0abc
3	5.7a	52.8ab	.36bc	5.4a	10.4abc
4	5.8a	53.0ab	.41ab	4.9abc	11.2abc
5	5.7a	45.1ab	.37ab	4.3c	9.1bc
6	6.5a	60.5a	.45a	5.3ab	13.0a
7	6.2a	55.0a	.42ab	5.0abc	11.8ab
8	6.2a	51.3ab	.41ab	5.1abc	11.1abc
			WISHKAH SOIL		
1	2.8c	15.2c	0.16c	1.3c	2.8c
2	5.5a	52.3a	.37a	5.5a	11.4a
3	4.2b	30.7bc	.25b	2.6b	5.6b
4	3.7bc	31.6b	.24bc	2.0bc	5.2b
5	3.7bc	28.1bc	.24bc	2.0bc	4.8bc
6	4.1b	28.7bc	.26b	2.3bc	4.8bc
7	3.9b	29.5bc	.28b	2.3bc	5.3bc
8	4.0b	30.3bc	.28b	2.2bc	5.3b

[1]Treatments: 1 = untreated control, 2 = 300 kg P/ha, 3 = 2 + 1800 kg Ca/ha, 4 = 3 + 75 kg Mg/ha, 5 = 4 + 100 kg K/ha, 6 = 5 + 75 kg S/ha, 7 = 6 + 0.1 kg Co/ha, 8 = 7 + 0.5 kg Mo/ha. Values are averages of 3 replications each. Within each soil, averages followed by different letters are significantly different at $p < 0.05$.

Bunker soil of experiment 1, P appeared to be the primary nutrient limiting growth in the Wishkah soil. The decreased growth responses to fertilizer mixtures were probably caused by nutrient interactions. Such interactions have been reported with red alder (Hughes and others 1968) and other forest tree species (Radwan and Shumway 1985). Use of fertilizer mixtures on red alder, therefore, is not advisable without further information.

Neither Co nor Mo appeared to affect growth in the Grove or Wishkah soils. Apparently, both soils contained enough of these elements to fully satisfy the growth requirements of red alder. Other possible sources of Co and Mo included fertilizer impurities and remnants of the nutrient solution used in production of the test seedlings. Results of greenhouse experiments by Russell and others (1968) suggest that the requirement for Co is quite low.

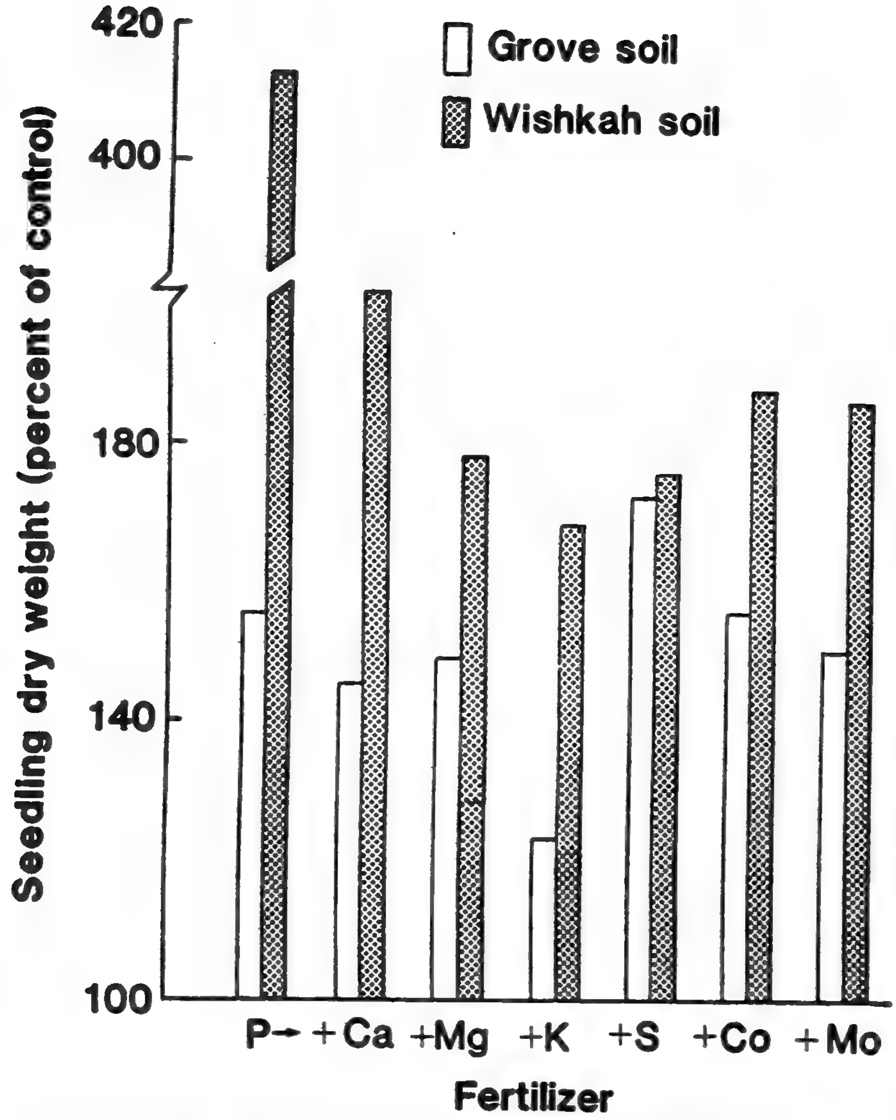

Figure 2—Effect of different fertilization treatments on seedling dry weight of red alder. Fertilizers were applied in the order shown in an additive manner; that is, P, P + Ca, P + Ca + Mg, and so on. Fertilizer sources and application rates are given in the text.

Foliar Nutrients

In both experiments, with few exceptions, concentration and content of the various foliar nutrients varied significantly by fertilizer. Also, in experiment 2, significant soil and soil x fertilizer interactions were found for concentration and content of several nutrients.

Experiment 1—Leaves from seedlings grown in Bunker soil were not analyzed. Leaves from all Bunker plants, except those from the P treatments, were very small and did not provide enough material for chemical analysis.

Nutrient concentrations in foliage of the unfertilized seedlings grown in Grove soil (table 4) were generally within the range of values reported in the literature for field-grown red alder (DeBell and Radwan 1984) and green alder (Grigal and others 1979, Henry 1973). Fertilization affected nutrient concentrations in foliage of the Grove seedlings, and trends varied by nutrient and rate of application. With only three exceptions (K-high, Mg-low, and Mg-high), fertilizers containing P, K, Ca, Mg, and S did not significantly increase the concentration of these nutrients in the foliage. This was probably caused by dilution resulting from increased growth (table 2). In contrast, some

Table 4—Effect of fertilization on foliar nutrients of red alder seedlings grown in Grove soil (Experiment 1)[1]

Treatment	N	P	S	Ca	K	Mg	Cu	Fe	Zn	Mn
	CONCENTRATION									
	Percent						Parts per million			
C	2.45ab	0.18bc	0.20a	0.97a	1.17a	0.23c	11ab	359a	89a	1367bc
P, low	2.44ab	.17c	.19ab	.88ab	1.07bcd	.23c	9ab	198bc	67ab	571def
P, high	2.69a	.17c	.18ab	.87ab	.86d	.23c	8b	133c	47b	294f
K, low	2.30b	.19ab	.18ab	.94ab	1.29ab	.24c	10ab	369a	92a	1726ab
K, high	2.19b	.18bc	.17b	.89ab	1.46a	.22c	10ab	306ab	92a	1880ab
Ca, low	2.41ab	.19ab	.18ab	.81abc	1.10bc	.19c	11ab	260abc	81a	660def
Ca, high	2.44ab	.18bc	.18ab	.85ab	1.01cd	.20c	11ab	173bc	72ab	406ef
Mg, low	2.21b	.18bc	.18ab	.90ab	1.09bcd	.36b	11ab	223abc	85a	1934ab
Mg, high	2.21b	.21a	.18ab	.84abc	1.10bc	.43a	12a	155bc	92a	2258a
S, low	2.41ab	.18bc	.20a	.76bc	1.24abc	.21c	11ab	275abc	74ab	1009cd
S, high	2.44ab	.18bc	.19ab	.66c	1.13bc	.20c	11ab	266abc	62ab	898cde
	CONTENT									
	Milligrams per leaf						Micrograms per leaf			
C	6.8d	0.5e	0.6c	2.7c	3.2b	0.6e	3b	98a	25ab	381cde
P, low	10.2bc	.7bcd	.8abc	3.7abc	4.5a	1.0cd	4ab	82a	28ab	234e
P, high	14.6a	.9a	1.0a	4.8a	4.6a	1.2bc	5a	72a	25ab	162e
K, low	7.2cd	.6cd	.6c	2.9bc	4.0ab	.7de	3b	116a	29ab	544cd
K, high	7.3cd	.6cd	.6c	2.9bc	4.8a	.7de	3b	101a	31ab	623bc
Ca, low	10.1bc	.8ab	.8abc	3.4bc	4.6a	.8de	4ab	109a	34ab	276e
Ca, high	12.0ab	.9a	.9ab	4.2ab	5.0a	1.0cd	5a	85a	35ab	201e
Mg, low	9.1bcd	.8ab	.7bc	3.7abc	4.5a	1.5ab	4ab	92a	35ab	799ab
Mg, high	8.5cd	.8ab	.7bc	3.2bc	4.3ab	1.7a	4ab	60a	36a	874a
S, low	8.1cd	.6cd	.7bc	2.6c	4.2ab	.7de	4ab	95a	25ab	350de
S, high	9.0bcd	.7bcd	.7bc	2.4c	4.2ab	.8de	4ab	98a	23b	332de

[1]C = untreated control. "Low" and "high" refer to application rates as follows: 150 and 300 kg P/ha, 100 and 200 kg K/ha, 1200 and 2400 kg Ca/ha, 75 and 150 kg Mg/ha, and 75 and 150 kg S/ha. Values are averages of 3 replications each. Within the "concentration" and "content" sections, averages followed by different letters are significantly different at $p < 0.05$.

fertilizers, especially when used at the high rate, significantly reduced the concentration of other nutrients in the foliage. Most notable reductions were in Fe, Mn, Zn, S, and Ca. Dilution by growth, changes in soil pH, and nutrient interactions were probably responsible for these reductions.

The individual fertilizers, especially when applied at the high rates, increased the content of their nutrients (that is, P, K, Ca, Mg, or S) in the foliage of the fertilized seedlings, and most increases were significant (table 4). Obviously, these gains

Table 5—Effect of fertilization on concentration of foliar nutrients of red alder seedlings grown in 2 forest soils (experiment 2)[1]

Treatment number	N	P	S	Ca	K	Mg	Cu	Fe	Zn	Mn
	Percent						*Parts per million*			
					GROVE SOIL					
1	2.34cd	0.12b	0.17b	0.83b	0.90b	0.19c	9ab	196ab	79a	1558a
2	2.24d	.12b	.16b	.99ab	.84b	.24b	7b	213a	59a	538b
3	2.42cd	.13b	.17b	.92ab	.93b	.19c	10ab	204ab	63a	787b
4	2.47bcd	.15ab	.18a	1.01a	.87b	.35a	9ab	191ab	72a	1198a
5	2.49bcd	.16a	.18a	1.05a	1.10a	.36a	9ab	181ab	90a	1546a
6	2.72ab	.17a	.19a	.89ab	1.21a	.31a	11a	199ab	80a	1315a
7	2.54abc	.16a	.18a	.93ab	1.15a	.32a	9ab	179ab	68a	1406a
8	2.77a	.17a	.19a	.91ab	1.21a	.32a	10ab	171b	87a	1300a
					WISHKAH SOIL					
1	2.40bc	0.12a	0.17b	0.42b	1.09a	0.34ab	13a	151b	132a	350a
2	2.33c	.12a	.17b	.71a	.55c	.34ab	6c	192a	68c	227a
3	2.52abc	.14a	.18ab	.75a	.82b	.29b	10b	159ab	88bc	207a
4	2.68a	.14a	.19a	.79a	.86b	.35a	11ab	145b	101ab	372a
5	2.52abc	.15a	.18ab	.82a	1.26a	.34ab	11ab	151b	123a	518a
6	2.66a	.15a	.19a	.78a	1.23a	.34ab	11ab	164ab	113ab	474a
7	2.63ab	.14a	.19a	.77a	1.25a	.33ab	10b	157ab	112ab	454a
8	2.72a	.14a	.19a	.70a	1.27a	.32ab	11ab	150b	109ab	475a

[1] Treatments: 1 = untreated control, 2 = 300 kg P/ha, 3 = 2 + 1800 kg Ca/ha, 4 = 3 + 75 kg Mg/ha, 5 = 4 + 100 kg K/ha, 6 = 5 + 75 kg S/ha, 7 = 6 + 0.1 kg Co/ha, 8 = 7 + 0.5 kg Mo/ha. Values are averages of 3 replications each. Within each soil, averages followed by different letters are significantly different at $p < 0.05$.

resulted from the uptake of the fertilizer nutrients by the seedlings. The fertilizers also increased foliar content of nutrients other than those contained in the fertilizers. Most increases were in contents of N, P, K, Ca, Mg, and S, with very few significant gains in the microelements. Fertilizers that resulted in the greatest gains in nutrient content were those containing P and Ca. These were also the most effective fertilizers for enhancing seedling growth, including dry weight of the leaves (table 2).

Experiment 2—With few exceptions, foliar-nutrient concentrations of the unfertilized trees grown in Grove soil in this experiment (table 5) were comparable to those of the Grove seedlings of experiment 1 (table 4). Presence of the forest floor on top of mineral soil in experiment 2, therefore, did not materially affect nutrient composition of the leaves. Leaves of the control seedlings grown in Wishkah soil were mostly higher in Mg, Cu, and Zn, and lower in Ca and Mn than were leaves of the Grove seedlings. The difference in foliar Ca and not Mg reflected the difference in Ca content between the

Table 6—Effect of fertilization on content of foliar nutrients of red alder seedlings grown in 2 forest soils (experiment 2)[1]

Treatment number	Nutrient: N	P	S	Ca	K	Mg	Cu	Fe	Zn	Mn
	Milligrams per leaf						*Micrograms per leaf*			
	GROVE SOIL									
1	6.5d	0.3c	0.5c	2.3b	2.5e	0.5c	3b	54c	22c	428b
2	8.9bcd	.5bc	.6bc	3.9a	3.3de	.9b	3b	84ab	23bc	214c
3	8.8cd	.5bc	.6bc	3.3a	3.4de	.7bc	4ab	74abc	23bc	277c
4	10.2abc	.6ab	.7ab	4.1a	3.6cde	1.5a	4ab	79ab	30abc	490ab
5	9.1bc	.6ab	.6bc	3.8a	4.1bcd	1.3a	3b	66bc	33ab	565a
6	12.3a	.7a	.9a	4.0a	5.5a	1.4a	5a	91a	36a	587a
7	10.7abc	.7a	.8ab	3.9a	4.9abc	1.3a	4ab	75ab	28abc	592a
8	11.4ab	.7a	.8ab	3.8a	5.0ab	1.3a	4ab	70abc	36a	538ab
	WISHKAH SOIL									
1	3.9c	0.2b	0.3c	0.7b	1.8c	0.5c	2a	25b	22a	58a
2	8.7a	.5a	.6a	2.7a	2.1bc	1.2a	2a	72a	25a	85a
3	6.4abc	.3ab	.4bc	1.9a	2.1bc	.7bc	2a	40b	22a	52a
4	6.5abc	.4ab	.5ab	1.9a	2.1bc	.9b	2a	35b	25a	89a
5	6.0bc	.4ab	.4bc	2.0a	3.0abc	.8bc	2a	37b	30a	124a
6	6.8ab	.4ab	.5ab	2.0a	3.2ab	.8bc	3a	42b	29a	123a
7	7.3ab	.4ab	.5ab	2.2a	3.5a	.9b	3a	44b	31a	127a
8	7.5ab	.4ab	.5ab	1.9a	3.5a	.9b	3a	41b	30a	131a

[1] Treatments: 1 = untreated control, 2 = 300 kg P/ha, 3 = 2 + 1800 kg Ca/ha, 4 = 3 + 75 kg Mg/ha, 5 = 4 + 100 kg K/ha, 6 = 5 + 75 kg S/ha, 7 = 6 + 0.1 kg Co/ha, 8 = 7 + 0.5 kg Mo/ha. Values are averages of 3 replications each. Within each soil, averages followed by different letters are significantly different at $p < 0.05$.

two soils (table 1). Differences between the two soils in content of other elements, such as N, P, K, and S (table 1), were also not reflected in foliar concentrations of those nutrients in leaves of the unfertilized seedlings of the two soils (table 5).

As in experiment 1, fertilization affected foliar nutrient concentrations of the seedlings grown in each of the two test soils (table 5). Effects were more pronounced with the macronutrients than the micronutrients. With few exceptions (Ca, Zn, and Mn), foliar nutrient concentrations of the fertilized trees did not vary much by soil. Also, in both soils, concentrations of most macronutrients became appreciably higher with the addition to the fertilizer mixture of Mg or Mg and K (that is, treatments P + Ca + Mg or P + Ca + Mg + K) and then remained essentially unchanged after additions of S, Co, and Mo fertilizers.

Unlike concentration, foliar-nutrient content of the control trees varied greatly by soil (table 6). On the average, contents of the Grove plants were higher than those of the Wishkah seedlings. This was particularly true for N, P, S, Ca, K, Cu, Fe, and Mn. Most of these differences can be attributed to the heavier leaves of the Grove plants (table 3) rather than to differences in foliar concentrations of the various nutrients (table 5).

In both soils, most fertilizers enhanced the content of foliar nutrients, although some increases were not significant. These gains, as in experiment 1, most probably resulted from parallel increases in dry-matter production (table 3) and nutrient uptake and utilization. For most nutrients, the nutrient additions resulting from fertilization were higher in the Grove than in the Wishkah plants, reflecting the heavier Grove leaves (table 3). Also, in general, nutrient content was affected most by the P + Ca + Mg + K + S treatment in the Grove soil and by the P fertilizer alone in the Wishkah soil. Again, differences in dry weight of leaves (table 3) were probably responsible for this result.

Conclusions

Results indicated that, under natural conditions, good growth of red alder cannot be expected on all forest soils. Like other plants, red alder will grow well only on sites where native soil nutrients are sufficient to meet the species' nutritional requirements for growth and development. Where native nutrients are not adequate, growth may be improved by application of the appropriate fertilizer(s). Data presented here demonstrate the potential of fertilization, especially with P fertilizer, to increase alder growth. The data also suggest caution in using combinations of fertilizers because such mixtures may materially reduce growth response.

This study was conducted with potted seedlings under lathhouse conditions, and results may not agree with those from field tests. Field experiments, therefore, are still required to test and expand upon the present findings.

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English Equivalents

1 hectare (ha) = 2.47 acres

1 millimeter (mm) = 0.039 inch

1 centimeter (cm) = 0.39 inch

1 liter (L) = 1.06 quarts

1 gram (g) = 0.03527 ounce

1 kilogram (kg) = 2.2046 pounds

°C = (°F - 32) /1.8

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Effects of P, K, Ca, Mg, S, Co, and Mo fertilizers on growth and foliar nutrients of red alder seedlings potted in Grove, Bunker, and Wishkah forest soils were determined. Growth in Grove soil was stimulated most by P, Ca, and P + Ca + Mg + K + S. Growth in Bunker soil was improved only by P. In Wishkah soil, best growth was obtained when P was used alone; all fertilizer mixtures produced less growth. Results indicated the potential of fertilizer to increase alder production and suggested caution in using fertilizer mixtures because they may materially reduce growth response.

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